Water Vapor Sensitivity Analysis for AVIRIS Radiative-Transfer-Model-Based Reflectance Inversion

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ABSTRACT

As with other imaging spectrometers, AVIRIS measures the upwelling spectral radiance incident at the sensor. Most research and applications objectives for AVIRIS are based on the molecular absorption and scattering features expressed in the surface reflectance. A number of radiative-transfer-model-based algorithms have been developed to invert the measured radiance to the apparent surface reflectance. These algorithms attempt to compensate for the effects of the atmosphere absorption, atmospheric scattering, and illumination. Water vapor is the primary absorbing component of the atmosphere in the solar-reflected portion of the spectrum. A sensitivity analysis has been performed to explore the error in derived reflectance that results from an error in knowledge of water vapor. A significant sensitivity of derived reflectance to knowledge of water vapor is shown. This paper presents the analysis and results of this investigation.

1. INTRODUCTION

The NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) measures spectra of the upwelling radiance from 400 to 2500 nm. The spectra are measured through 224 channels with nominally 10-nm spectral sampling and 10-nm-wide Gaussian shaped spectral response functions. From an altitude of 20 km, the spectra are measured as 11- by up to 100-km images with 20-m spatial resolution. While AVIRIS measures radiance, the majority of science research and applications for AVIRIS are based in the molecular absorption and constituent-scattering characteristics expressed in the surface reflectance. The upwelling spectral radiance measured by AVIRIS is a result of solar illumination, atmospheric absorption, atmospheric scattering, and the reflectance of the surface. Water vapor is the dominant absorbing component of the atmosphere in this portion of the spectrum. Figure 1 shows three upwelling radiance spectra modeled with the MODTRAN radiative transfer code (Berk et al. 1989). For these modeled spectra constant 0.25 reflectance surface was illuminated at a 45-degree solar zenith angle through the mid-latitude summer atmosphere. The differences in the three spectra are due solely to the amount of water vapor included in the modeled atmosphere. Almost every part of the spectrum is impacted by water vapor absorption. To derive the apparent surface reflectance from AVIRIS-measured radiance (Green et al. 1993) the atmospheric water vapor must be assessed and compensated. This paper presents a sensitivity analysis that explores the relationship between errors in knowledge of water vapor and the resulting errors in the derived apparent surface reflectance.

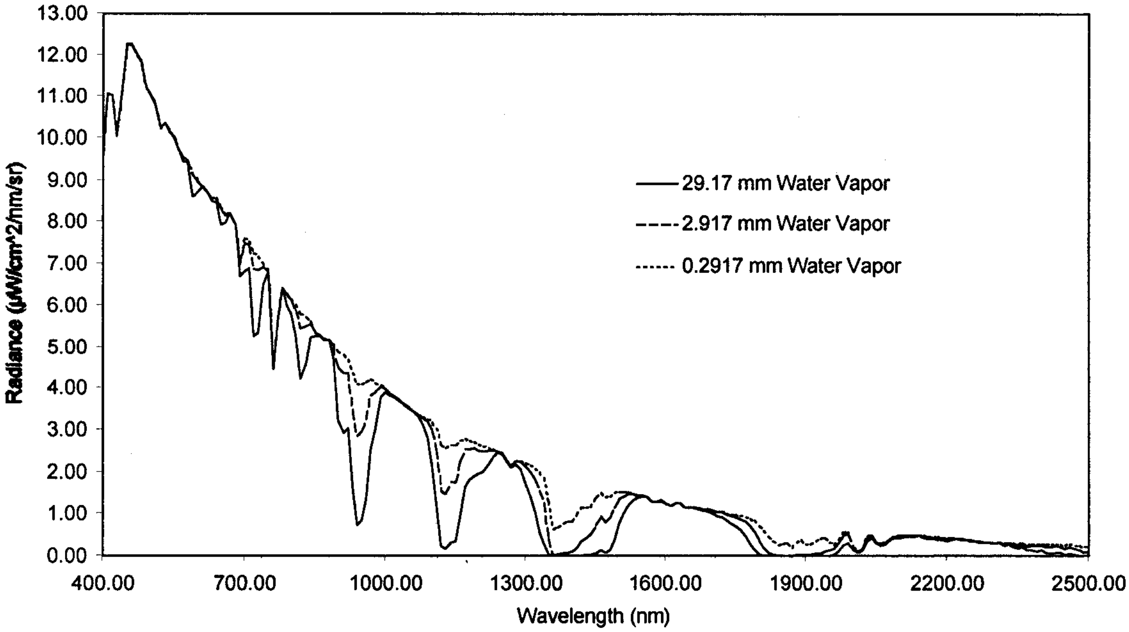

Figure 1. Modeled radiance for a range of water vapor in the atmosphere.

2. ANALYSIS

A number of radiance-to-reflectance inversion algorithms rely on a radiative transfer code to model and compensate for the atmosphere (Green et al. 1991a, Gao et al. 1991a, Adler-Golden et al. 1999). An analysis has been performed to assess the sensitivity of this approach to accurately knowing the amount of atmospheric water vapor. For this analysis a baseline radiance spectrum was calculated with the MODTRAN radiative transfer code and convolved to the spectral resolution of AVIRIS. Additional radiance spectra were modeled by varying the amount of water vapor . Figure 2 shows the baseline spectrum with 29.17 precipitable mm of water vapor, as well as a spectrum with 10 % less, or 26.25 precipitable mm of water vapor. The two spectra appear nearly identical. However, in regions of water vapor absorption at 940, 1150, 1380, 1900, and 2500-nm small absolute differences are evident. These differences in the low signal areas of the spectra provide the basis for sensitivity of radiative-transfer-model-based reflectance inversion to the knowledge of water vapor amount. To assess this sensitivity MODTRAN was used to calculate the path radiance as well as the reflected radiance for a spectrum with a reflectance of 1.0 and with water vapor amounts of ±10, ±5, and ±1 % of the baseline radiance spectrum. The reflected radiance is calculated as the total radiance of the 1.0 reflectance spectra minus the path radiance. Except for water vapor, the atmospheric and illumination conditions were identical to those of the baseline. All spectra were convolved to the nominal AVIRIS spectral resolution of 10-nm sampling and 10-nm-wide Gaussian response functions. The simple formula of Equation 1 was used to invert the baseline radiance to apparent surface reflectance.

Reflectance = (Baseline_Radiance – Path_Radiance) / (1.0_Reflected_Radiance) (1)

The surface reflectance was calculated for the baseline radiance using the path radiance and 1.0 reflected radiance for the designated errors in knowledge of water vapor.

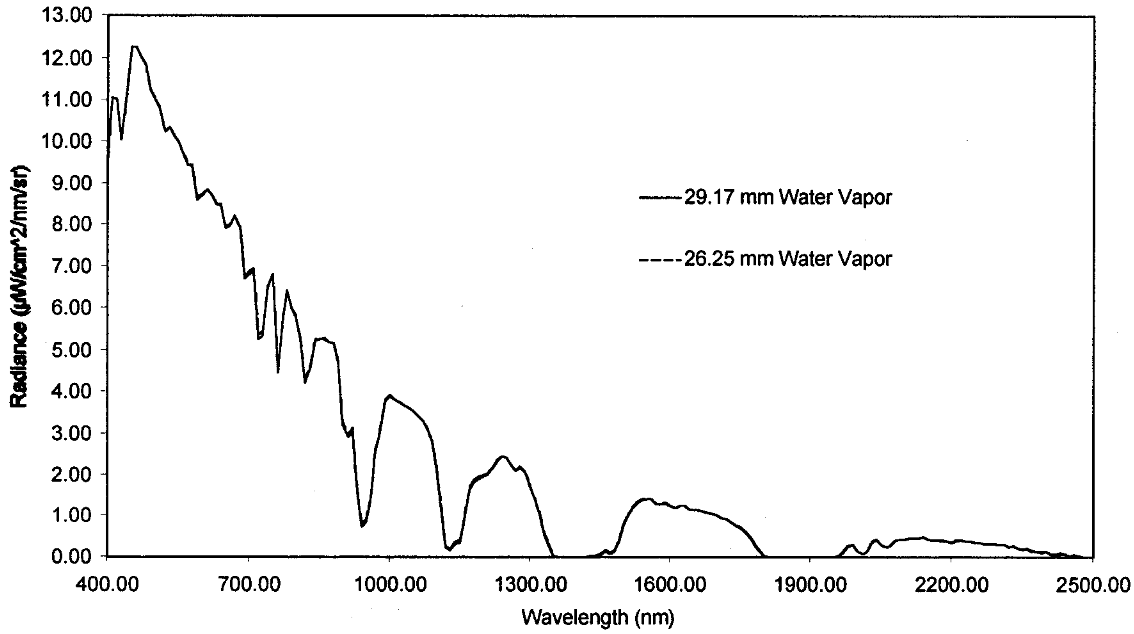

Figure 2. A modeled radiance spectrum and radiance spectrum with 90 percent of the baseline water vapor.

3. RESULTS

The percent error in derived reflectance induced by the error in knowledge of water vapor was calculated for each water vapor case. Figure 3 shows the percent error in reflectance that resulted across the solar reflected spectral range. As expected the errors are greatest in the regions of strong water vapor absorption. The level of the error in reflectance is significant in the regions of the 940, 1150, 1380, 1900, and 2500 nm water vapor absorptions. In each of these regions an error of 10% in water vapor caused in errors of greater than 10% in reflectance. Wide zones of the solar-reflected spectrum are impacted from errors in knowledge of water vapor.

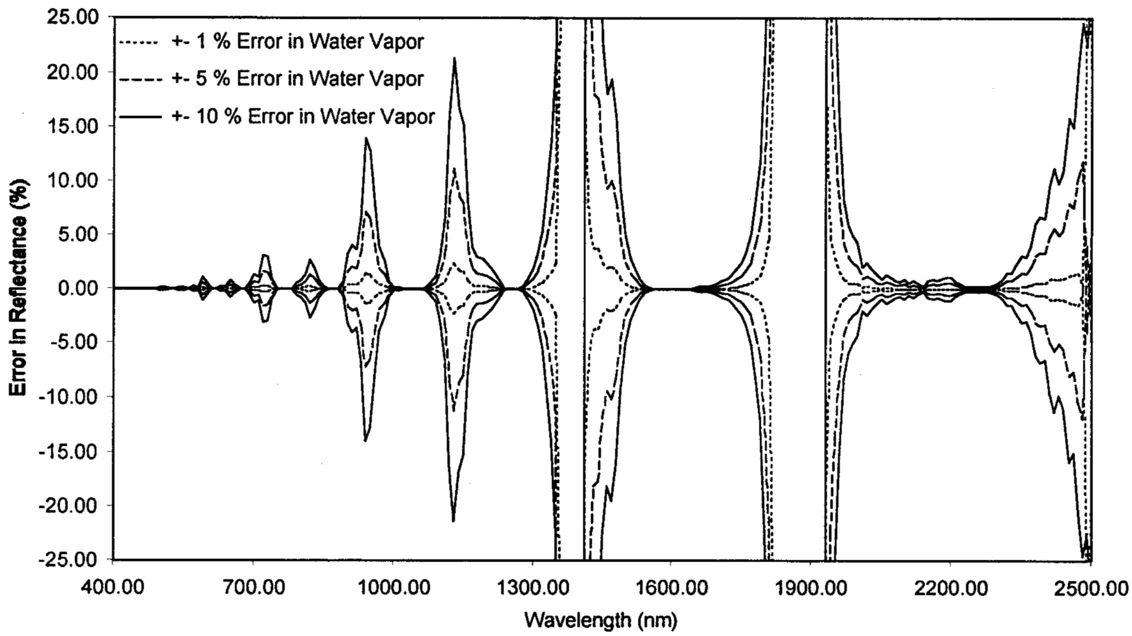

Figure 3. Percent error in derived reflectance induced by errors in knowledge of water vapor.

Derivation of reflectance for the baseline radiance with a 0.25 reflectance using a radiative transfer code approach has been shown to be significantly sensitive to the accuracy of the knowledge of atmospheric water vapor. To better understand the potential effect of these errors, one vegetation and one mineral spectrum have been included in the analysis. Figure 4 shows the errors in the derived reflectance spectrum for a vegetation spectrum over the range of errors in knowledge of water vapor. These errors in derived reflectance distort and shift the actual molecular absorption and scattering signatures found in vegetation. Figure 5 shows the effect that errors in knowledge of water vapor have on the derived reflectance spectrum of the mineral Jarosite. As with vegetation, the errors in derived reflectance distort and shift the inherent molecular absorption features of the mineral. Errors in the derived reflectance of vegetation, minerals, and other surface materials are induced by errors in knowledge of water vapor. Such errors undermine the science research and applications objectives for which imaging spectrometer data sets are measured.

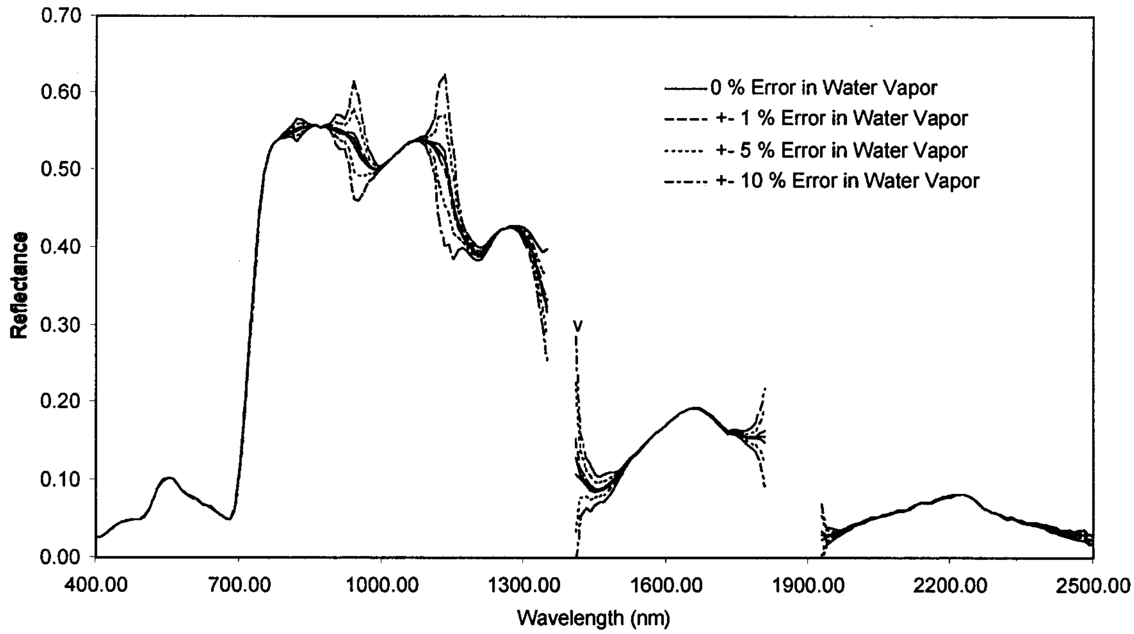

Figure 4. Errors in a derived vegetation reflectance spectrum induced by errors in knowledge of water vapor.

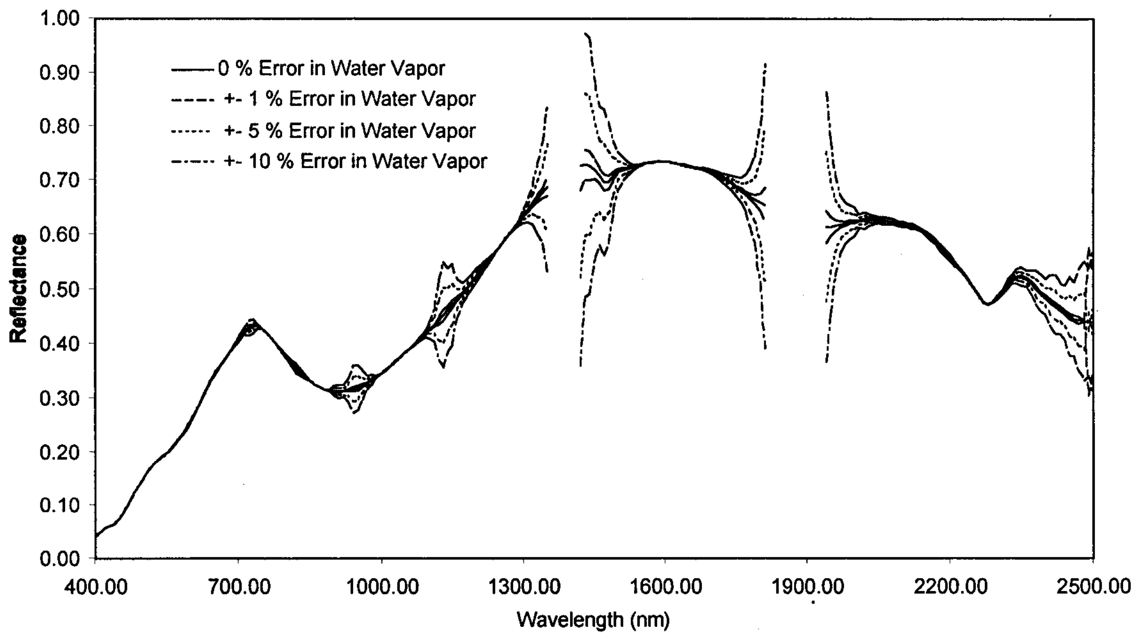

Figure 5. Errors in a derived Jarosite mineral reflectance spectrum induced by errors in knowledge of water vapor.

4. DISCUSSION

Knowledge of water vapor has been shown to be critical to the derivation of reflectance from measured radiance using a radiative-transfer-code-based method. Understanding this sensitivity is important because water vapor is highly variable in the environment. As an example, Figure 6 shows an AVIRIS image of the Pasadena, California area acquired on 18 May 1998. The image includes the San Gabriel Mountains at the top and the 210 Freeway through Pasadena at the bottom. The Rose Bowl stadium is evident at the left edge of the image. Figure 7 shows the derived water vapor (Green et al. 1991b, Green et al. 1993) from every spectrum in the AVIRIS image. Water vapor amounts as low as 5 preciptable mm are derived in the upper San Gabriel Mountains. Water vapor amounts as high as 15 precipitable mm are derived at the lower altitudes in Pasadena. This range of variation corresponds to a 300 % change in water vapor and occurs over less than a 10-km distance. The baseline sensitivity analysis of this paper showed that radiative-transfer-model-based reflectance inversion was sensitive to knowledge of water vapor at the 10% level. In review of the AVIRIS data collected since 1997, water vapor amounts ranging from 0.4 to 40.0 precipitable mm have been observed. Through these analyses, water vapor is confirmed to be an extraordinarily variable in actual imaging spectrometer measurements of the Earth's environment.

Figure 6. AVIRIS image of Pasadena, CA with the San Gabriel Mountains at the top.

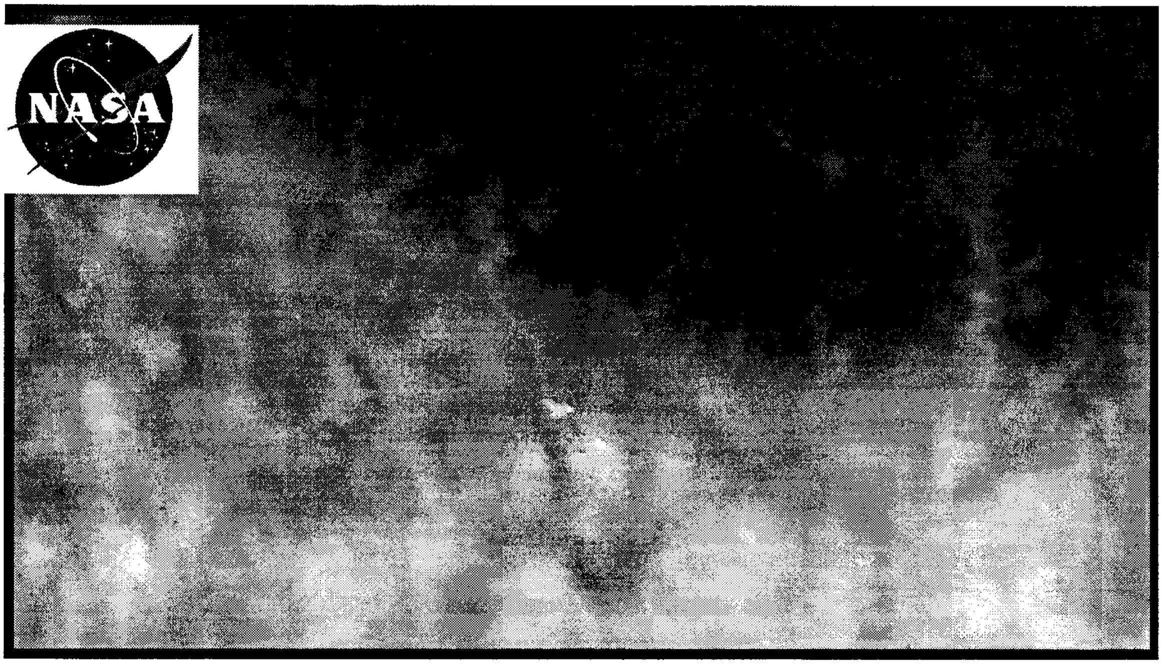

Figure 7. AVIRIS-derived water vapor for Pasadena, CA. Water vapor ranges from 15 precipitable mm in Pasadena to 5 precipitable mm in the San Gabriel Mountains.

5. CONCLUSION

Accurate knowledge of water vapor for every spectrum in an image is essential for radiative-transfer-based inversion of measured radiance to apparent surface reflectance. The errors in reflectance induced by errors in water vapor knowledge distort and shift the inherent molecular absorption and scattering signatures of surface materials. These distortions and shifts will in turn undermine the science research and applications objectives for which the imaging spectrometer data were measured. The high spatial and temporal variability of water vapor in the Earth's environment strengthens the need for accurate knowledge of water vapor for the derivation of apparent surface reflectance. Water vapor amounts must be know to at least at the 5% level, with a goal of 1%, in order to derive apparent reflectance spectra without significant errors. The water vapor amount must be known at these level of accuracy's for every spectrum in the image.

5. REFERENCES

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7. ACKNOWLEDGEMENTS

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